

**PILOT: Unlocking Body Memories for Creativity**  
**NSF Creative IT 0757370**  
Georgia Institute of Technology  
Final Project Report  
2008-2011

## **I. Participants**

### **1. What people have worked on the project?**

#### **Faculty:**

Ali Mazalek (Assistant Professor, Georgia Institute of Technology)—Principal Investigator. Responsible for overall project management and coordination; lead the creation of physical interaction technologies to control movement in 3D virtual worlds.

Michael Nitsche (Associate Professor, Georgia Institute of Technology)—Co-Principal Investigator. Project management and coordination; lead the design and development of 3D virtual worlds for displaying movements created through physical interaction technologies.

Sanjay Chandrasekharan (Postdoctoral fellow, Georgia Institute of Technology)—Lead the experimental aspect of the project, testing the projection of movement onto 3D avatars and improvement in cognitive tasks.

Timothy Welsh (Associate Professor, University of Toronto, Ontario, Canada)—Provided guidance on the cognitive sciences and experimental aspects of the project.

#### **Students:**

Paul Clifton (PhD Digital Media, Georgia Tech)—Preparation and running of the different experiments throughout the project; development and maintenance of sensing technologies for the physical puppet interface. [Y1-Y3]

Matthew Drake (MS Digital Media, Georgia Tech) —Preparation and running of pilot experiment with stroke patients and experiments to test effects on artistic expression; reimplementing of the virtual game in the Unity 3D engine. [Y3]

Firaz Ahmed Peer (MS HCI, Georgia Tech)—Preparation and running of experiments to test the projection of movement onto a 3D virtual avatar and experiments to test improvement in cognitive tasks; development of a second version of the puppet interface for use in the experiments. [Y2-Y3]

Andrew Quitmeyer (MS Digital Media, Georgia Tech) —Preparation and running of experiments to test the projection of movement onto a 3D virtual avatar and experiments to test improvement in cognitive tasks; development of the mental rotation game in the 3D virtual environment. [Y2]

Geoffrey Thomas (PhD Digital Media, Georgia Tech)—Coordination of experiments to test the projection of movement onto visual abstractions of those movements; development of physical puppet interface to control movement in 3D virtual worlds. [Y1]

Tandav Krishna (MS HCI, Georgia Tech)—Preparation and running of experiments to test the projection

of movement onto visual abstractions of those movements. [Y1]

Martin Rojas (BS Computational Media, Georgia Tech)—Assisted in the development of the 3D renderer; developed an animation recorder based on game interfaces. [Y1]

## **2. What other organizations have been involved as partners?**

We have collaborated with the Faculty of Physical Education and Health at the University of Toronto and with the Department of Medical Rehabilitation at Emory University.

## **3. Have you had other collaborators or contacts?**

The project was a collaboration between two research groups in the School of Literature, Communication & Culture at the Georgia Institute of Technology: the Synaesthetic Media Lab (SynLab) directed by Ali Mazalek and the Digital World and Image Group (DWIG) directed by Michael Nitsche.

In addition, we worked with Sanjay Chandrasekharan, a postdoctoral fellow with the School of Interactive Computing at the Georgia Institute of Technology, and with Tim Welsh from the Faculty of Physical Education and Health at the University of Toronto.

In the first year of the project we also hired Friedrich Kirschner as an expert on real-time 3D engines for puppeteering. Kirschner worked off campus and communicated weekly via video conferencing. He is an independent scholar associated with the Interface Cultures program at Linz who is an internationally acclaimed expert in this specific area of real-time puppeteering. His expertise is not only in the implementation of 3D puppet applications but he also works as an artist who uses these tools in his artistic practice. He was seminal in the fast and reliable transition of the 3D renderer into the current open source version.

We have also discussed a potential collaboration focusing on creativity in performance arts with Prof. Michael Neff from the University of California, Davis.

We also began a new collaboration with a brain-machine interface group led by Prof. Melody Moore Jackson from the School of Interactive Computing at the Georgia Institute of Technology and with Prof. Andrew Butler from the Department of Medical Rehabilitation at Emory University in order to examine possible medical applications of the puppet.

# **II. Activities and Findings**

## **1. What were your major research and education activities?**

### **Research Activities:**

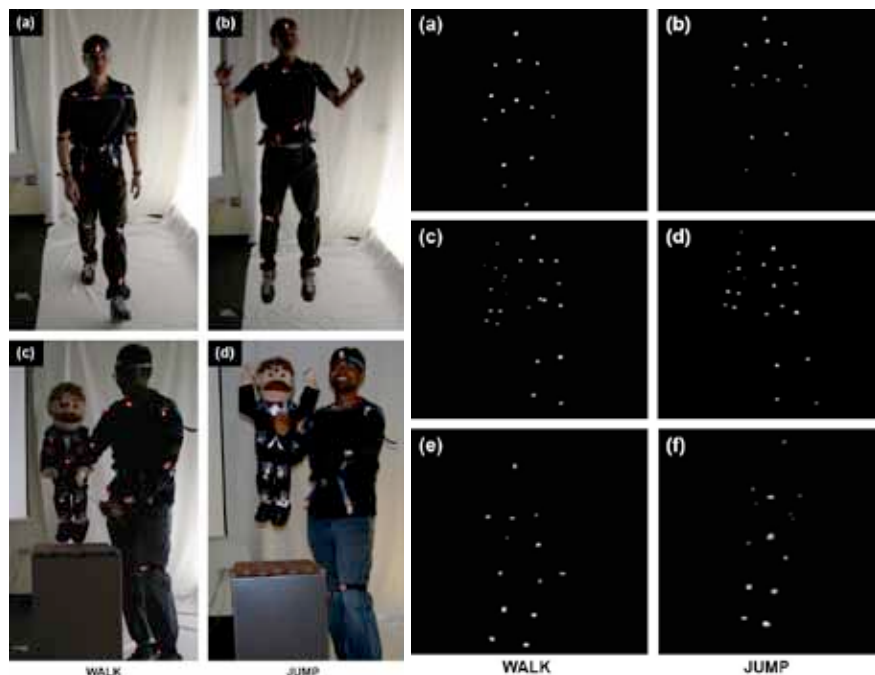
Our research has investigated the cognitive connection players create between their own bodies and the virtual bodies of their interactive avatars through tangible interfaces. The work is driven by experimental results showing that execution, perception, and imagination of movements share a common coding in the brain, which allows people to recognize their own movements better. We are interested in this connection because it creates a channel wherein players make a direct connection between their own physical movements and those of the virtual avatar. We believe this channel can be used to transfer novel movements executed by the character on screen back to the player, via the common coding between perception of movements and imagination/execution of movements. This technological and theoretical development and approach has applications in medical rehabilitation, e.g. for patients with stroke or movement disorders. We summarize:

- 1) Our initial experiments investigating the connection between player and abstracted virtual avatar,

- 2) The resulting development of a full-body puppet interface for virtual character control that was designed based on common coding principles,
- 3) Our experiments demonstrating that the puppet interface is effective in 'personalizing' an avatar, by transferring a player's own movements to the virtual character,
- 4) Our experiments investigating whether perceiving this 'personalized' video game character executing novel body movements can lead to improved cognitive performance of the player.
- 5) Our experiments investigating whether perceiving this 'personalized' video game character executing novel body movements can lead to changes in player's artistic expression, and
- 6) Our pilot experiments with stroke patients exploring the potential for using puppet-like interfaces in medical rehabilitation.

### 1) Player Self-Recognition in Virtual Avatars [Y1]

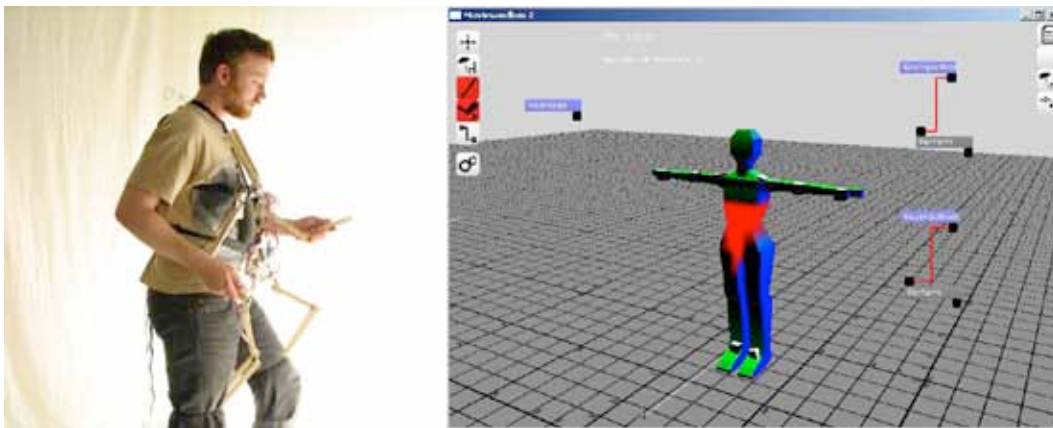
Our initial experiments investigated the extent of the connection between the player's own movement and that of a virtual character (see Mazalek et al., 2009). There were two types of experiments. The first type analyzed participants' ability to recognize their body movement, when shown in a visually abstracted form and either proportionally correct or proportionally standardized. The second type analyzed participants' ability to recognize the way they move a puppet, when shown in a visually abstracted form and with the puppeteer either present or not. Figure 1 shows how body movements of the participant and puppet were tracked by placing LED markers at key points on their bodies (left) and abstracted into points of light (right). These studies enabled us to establish the spectrum of self-recognition. In particular, we were interested in discovering whether players are able to recognize the movements they make while using a control interface (like a puppet) in order to determine whether using a tangible interface (e.g. a puppet rather than body motion capture) is effective for personalizing a game avatar.



**Figure 1.** (left) Walk and jump movement tracking with LED straps attached to: participant body (a & b) and both puppet and participant bodies (c & d); (right) Video stills of visually abstracted walk and jump movements for: participant body (a & b), participant body with puppet (c & d), and puppet only (e & f).

## 2) Full-Body Puppet Interface for Virtual Character Control [Y1-Y3]

Building on the results of the experiments described above, we designed a tangible puppet interface to encourage a direct means of transferring a player's movement to a virtual 3D character (see Figure 2). In comparison to full-body interaction approaches such as motion capture systems, puppets provide a low cost and portable approach for transferring player movements to 3D virtual characters. It is so effective that puppeteering is a dominating paradigm for current video game control mechanisms. Unfortunately, commercially available control systems (like those used in game consoles) present a disconnect with the player's own body movement, because even motion-controlled input devices such as the Wii controller or the Sony Move use heavily simplified mappings. In comparison to the level of abstraction in most commercial game controllers (gamepads, joysticks, keyboards), a puppet is tangible and can provide direct access to many degrees of freedom in the physical world, which can be mapped to a high level of resolution in the movements of the virtual characters. The abstraction of a puppeteering device thus allows players to execute actions in virtual space impossible in real space, while their body movements still map directly onto the virtual performer.



**Figure 2.** User wearing the full-body puppet interface (left) and virtual avatar controlled by the puppet (right).

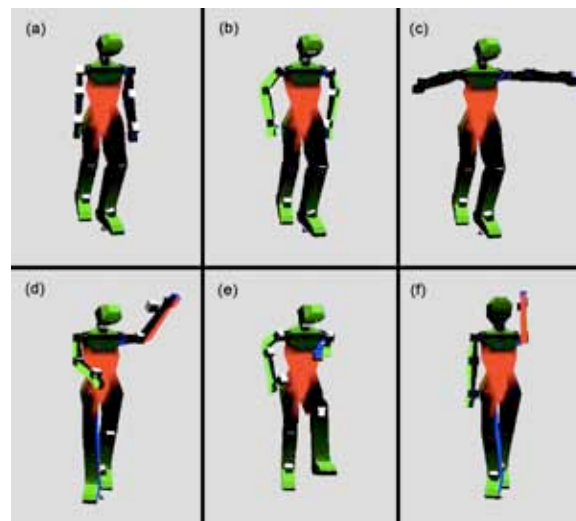
The puppet is a hybrid full-body puppet that is strapped to the player's body, and controlled by the player's arms, legs and body. This approach provides a high level of articulation and expressiveness in movement without requiring the skill of a professional puppeteer. The puppet consists of 10 joints at the knees, hips, waist, shoulders, elbows and neck, allowing us to capture a range of movement data. It is built out of wooden "bone" pieces that are connected across the joints using potentiometers (one or two depending on the number of axes of rotation of the joint). The puppet's feet attach to the player's knees, its head attaches to their neck, and its midsection attaches to their waist. The player uses their hands to control the arms of the puppet. This configuration allows the puppet to be easily controlled by both the hand and full-body movements of the player, and allows the puppet to faithfully transfer the player's own movements to their virtual avatar. While not implemented in the current version, the full-body puppet form factor could also enable us to incorporate feedback into the puppet device (e.g. using vibrating motors at the joints). This would allow the virtual avatar's movements to feed back into the physical device and stimulate player movements. This sort of enhancement could be useful for teaching certain movements (e.g. in a workflow) or in rehabilitation applications.

We have maintained and improved the puppet interface throughout the duration of the project and have constructed several different versions. In the final year, we improved the industrial design of the puppet for use in our pilot experiments with stroke patients. Based on this work, we also did some exploratory design and testing work to investigate the development of modular puppets that could be customized for different users (e.g. to allow different limb lengths) and that could incorporate tactile feedback at the joints. We tested different kinds of sensors for this purpose, such as fabric based sensors, and constructed a single modular joint (elbow) that incorporates both movement sensing and tactile feedback.

Movement data from the puppet is wirelessly transmitted to our 3D renderer, allowing the physical puppet interface to steer a virtual puppet in real-time. The renderer allows us to create and deploy games that make use of the puppet interface. The renderer uses XML files to store the scenes and settings for the characters allowing for very flexible usage. In addition to character control, the application currently supports camera placement, panning and tilting. The 3D renderer also includes advanced import functions for standard 3D modeling files and has basic animation recording options. Our first version of the renderer was based on the Moviesandbox (MSB) application, an open-source, OpenGL-based, machinima tool written in C++ ([www.moviesandbox.net](http://www.moviesandbox.net)). In Y3, we moved to the Unity 3D engine, which allows for even greater flexibility and provides better support for game development.

### 3) Player Self-Recognition in Virtual Avatars Controlled with the Puppet Interface [Y2]

We conducted two experiments to assess the hypothesis that a person can identify her own movement even when the movement is instantiated by an avatar (see Mazalek et al., 2010). Our first experiment analyzed players' ability to recognize their body movement in different types of walking: normal walk, hip-walk and arm-out-walk. The second experiment analyzed participants' ability to recognize their movements when they performed while standing in a fixed location. Movements here were: tossing an item, twisting and drinking an imaginary beverage. In both experiments, the participants used the puppet controller described above. Figure 3 shows screen captures of the avatar doing the walking and standing movements.



**Figure 3.** Stills of the 3D avatar in the walking movements (walk (a), hip-walk (b), arm-out-walk (c)) and in the fixed position movements (toss (d), twist (e), drink (f)).

### 4) Enhancing Player Cognitive Performance using the Puppet Interface [Y2]

Building on the above results, we conducted two experiments, using a novel game developed in our 3D engine. The game was designed to investigate two research questions. First, we wanted to examine how the puppet performed as a control interface, in relation to standard interfaces such as joysticks and keyboards. Secondly, we wanted to examine how the embodied interaction between the player and the virtual avatar might contribute to the player's cognitive skills, specifically mental rotation. To examine the first question, we needed a 'neutral' task, different from standard tasks seen in games, because if game-related tasks are used, expert game players would perform at high levels, and possibly skew the data towards standard interfaces. Further, the puppet interface affords novel forms of interactions within video games, and we therefore wanted to develop a task not commonly seen in standard video game interactions. To examine the second question, we needed a task where the user imagined movements not commonly executed in the real world, so that we could examine the cognitive effects of this imagination in isolation from any previous motor training.

Based on these experimental constraints, we developed a game where players saw objects (teapots) appear in proximity to their 3D avatar, and they had to move their body and the puppet interface to make the virtual avatar touch these objects (see Figure 4). The teapots appeared randomly at different points near the avatar, and the user had to move her hands or feet to make the avatar touch the teapot. To make the task different from game-like tasks, the renderer's camera slowly rotated around the avatar in an unpredictable manner, making the avatar float in space in different orientations. This apparent movement of the avatar forced the player to reconsider the position and orientation of the virtual avatar in relation to the interface strapped to their body. Once touched, each teapot disappeared and a new one appeared in a different location. The player's goal was to touch as many teapots as possible in the time provided (13 minutes). The number of teapots touched, and the time taken to touch each teapot were tracked by the system.



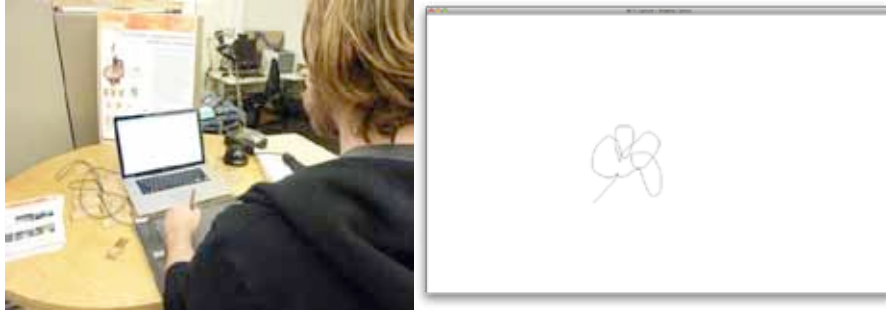
**Figure 4.** User wearing the full-body puppet and trying to touch a teapot in the virtual contact game.

## 5) Affecting Player Artistic Expression using the Puppet Interface [Y3]

Based on the previous studies, we designed and conducted a test of the impact of the puppet interaction on a person's artistic creativity. The experiment tested whether playing a video game using our puppet interface leads to changes in the way participants express themselves through sketching. The experiment involved playing the video game in three different mapping conditions (between player movements and the speed of the avatar movements), and drawing two pictures before and after the game. We examined how the different game conditions influenced the drawings. The hypothesis was that different mappings between player movements and avatar movements would lead to analogous changes in the drawings.

The experiment asked participants to first draw two sketches (a four-leaf clover and a smiley face) using the BETS (Behavioral Traits from Sketches) software system. BETS is tool that was built in our previous research that records data (speed and pressure) of drawings made using a WACOM digital tablet and pen (see Figure 5). After the first BETS task, participants played our teapot touching game (this time with a static camera perspective) with a normal real-to-virtual movement mapping (i.e. the avatar moved at the same speed as the participant). After playing the game until a proficiency threshold was reached, participants repeated the drawing task using the BETS system. Next, participants played the teapot game again, however this time the avatar moved either with slower or faster responses in the 3D world (manipulated conditions) or with the same one-to-one (normal) mapping. Finally, participants once again completed the drawing task using the BETS system. We examined how the relative mapping conditions affected participants' pressure and speed of drawing.





**Figure 5.** Example of a participant using the BETS system to draw a clover (left); screen shot of the clover drawn using BETS (right).

## **6) Piloting Puppet Acceptability with Stroke Patients [Y3]**

Based on the results of our previous studies, we projected that there may be a potentially beneficial application of this system for stroke rehabilitation. Towards this goal, we conducted a pilot study to see how receptive stroke patients are to an in-house rehabilitation gaming system using the puppet.

This pilot experiment assessed whether participants like using our game controller device (puppet) to navigate a virtual environment. This puppet is a non-significant risk device but offers distinct design and patterns of use that might affect usability for individuals who have undergone a stroke. During the experiment, stroke patients played the teapot touching game described above, however the camera remained static, and teapots appeared in only nine possible locations (3 rows x 3 columns in front of the avatar to the left/center/right and top/middle/bottom). We monitored each participant's performance during the game phase and then asked a series of follow-up questions to gather feedback about how much the participant liked the puppet. Finally, participants evaluated the qualities of the puppet and virtual experience in an open-ended interview.

### **Education Activities:**

The project has been a central part of ongoing group work in the Synaesthetic Media Lab as well as in the Digital World & Image Group, and two related graduate level studio courses taught by Mazalek and Nitsche. The project has been presented in these courses and discussed in the context of embodied cognition, movement projection, and body memory.

We have not yet directly implemented the project into any existing syllabus but graduate and undergraduate students have been involved in the project continuously through research-based independent study courses.

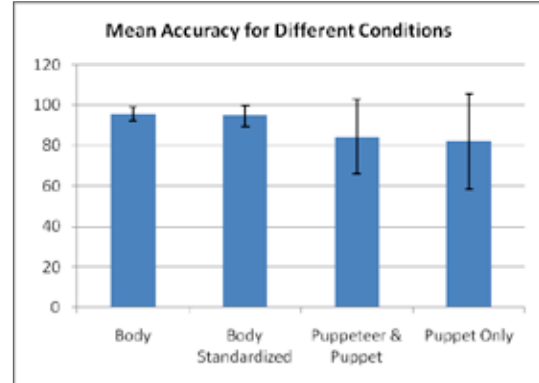
## **2. What are your major research findings?**

We describe our research findings from the experiments described above.

### **1) Player Self-Recognition in Virtual Avatars [Y1]**

These experiments investigated the extent of the connection between the player's own movement and that of a virtual character (see Mazalek et al., 2009). Participants showed high levels of identification in all studies (see Figure 6). All accuracy measures were significantly above chance level. The high standard deviations in the last two conditions are due to one participant performing very poorly, averaging 40 and 31.6 percent correct scores, and another participant scoring 100%. Overall, the results showed an effective translation of self to the character, suggesting that we indeed project ourselves to the movements of characters whose movements derive in second order from our own body memory; probably through a common coding system.

	Accuracy	SD	$\chi^2$	p
<b>Body</b>	95.71%	3.49	296.51	<.00001
<b>Body Standardized</b>	94.71%	5.42	283.22	<.00001
<b>Puppeteer &amp; Puppet</b>	84.33%	18.36	177.86	<.00001
<b>Puppet</b>	82%	23.5	182.73	<.00001

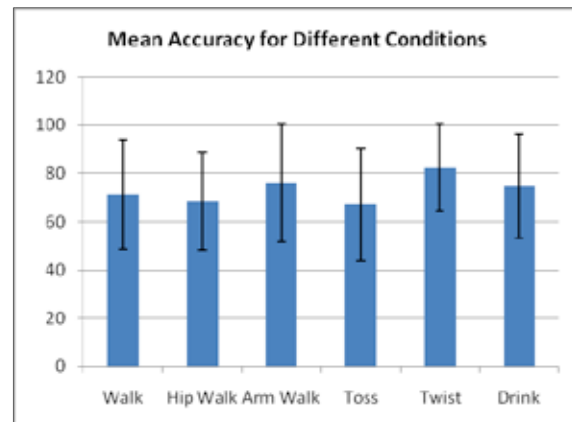


**Figure 6.** Self-recognition accuracy results in the four experimental conditions: body, body with standardized proportions, puppet with puppeteer present, and puppet alone.

## 2) Player Self-Recognition in Virtual Avatars Controlled with the Puppet Interface [Y2]

The goal of these experiments was to assess the hypothesis that a person can identify her own movement even when the movement is instantiated by an avatar (see Mazalek et al., 2010). Participants showed high levels of identification in both experiments (see Figure 7). All accuracy measures were significantly above chance level. The high standard deviations suggest significant individual differences, and follow the pattern in our previous experiment and other studies in the literature. The recognition rate is not as high as the recognition of own body movements in a point-light-walker video (~95%) but comparable to the self-recognition of a point-light-animation recorded from the movements of a hand puppet operated by a non-professional puppeteer (~80%). The difference between the hand puppet movement recognition and the more complex hybrid marionette recognition presented in this paper could be explained by the unfamiliarity with the interface. We believe the recognition levels could be raised further by improving the avatar's visual presentation and movement patterns. Overall, the results show that players can recognize their own movements if they are transferred to an avatar using a puppet interface. We believe these results could be exploited to develop new media, new interfaces, and also new applications for video game and digital media, particularly in the medical field.

	Accuracy	SD	$\chi^2$	p
<b>Walk</b>	71.21%	22.54	72.54	<.001
<b>Hip Walk</b>	68.43%	20.20	56.54	<.001
<b>Arm Walk</b>	76.01%	24.36	96.66	<.001
<b>Toss</b>	67.17%	23.28	62.72	<.001
<b>Twist</b>	82.32%	18.03	106.36	<.001
<b>Drink</b>	74.75%	21.47	82.00	<.001



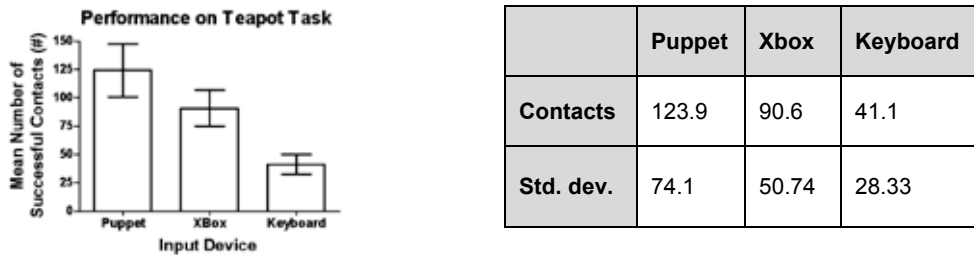
**Figure 7.** Self-recognition accuracy results in the three walking (walk, walk with hand on hip, walk with arm extended) and three standing (toss a ball from one hand to the other, do a twisting movement, drink from a cup)

## 3) Enhancing Player Cognitive Performance using the Puppet Interface [Y2]

These experiments investigated two research questions. First, we wanted to examine how the puppet performed as a control interface, in relation to standard interfaces such as joysticks and keyboards. Secondly, we wanted to examine how the embodied interaction between the player and the virtual avatar



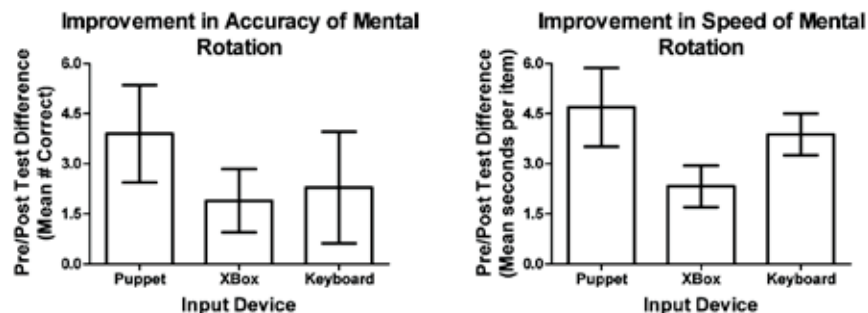
might contribute to the player's cognitive skills, specifically mental rotation. The studies involved 30 participants playing the teapot game described above. There were 3 interface conditions (puppet, Xbox controller, keyboard), and 10 people played the game using one of the interfaces. 15 of the participants (50%) were female (5 in each group). The two experiments (teapot touching and mental rotation) were conducted concurrently. The participant was first asked to do two sessions of a standard mental rotation test. After this, the participant was asked to play the teapot touching game using one of three control interfaces: the puppet, an Xbox controller, or a keyboard. After they had played the game for 13 minutes, participants did two sessions of the mental rotation experiment again.



**Figure 8.** The average number of teapots touched across the three conditions (puppet, Xbox and keyboard).

To determine if the puppet device has performance advantages over the more conventional devices, we analyzed the mean number of successful teapot contacts (Figure 8). Performance advantages of the puppet over the Xbox controller, although numerically large, only tended toward statistical reliability ( $p < .13$ ). Despite the absence of a statistically reliable difference, effect size calculations of the differences between puppet and Xbox controllers were in the medium range (Cohen's  $d = .52$ ) suggesting important functional and practical differences in performance. The puppet group showed improvement in mental rotation accuracy as well, but this trend needs to be established more clearly, as the numerical difference between the puppet and the other groups, though large, were found to be not statistically significant (3-way ANOVA). However, t-tests of pre and post mental rotation performance showed that only the puppet group improved significantly (Figure 9).

	Puppet Pre/Post		Xbox Pre/Post		Keyboard Pre/Post	
<b>Accuracy</b>	15.1	19.0	15.5	17.4	16.5	18.8
<b>Std. Dev.</b>	6.2	6.6	7.1	6.5	4.8	5.2
<b>Time</b>	11.9	7.2	9.43	7.1	14.38	10.5
<b>Std. Dev.</b>	3.7	2.7	3.7	3.5	7.3	7.8



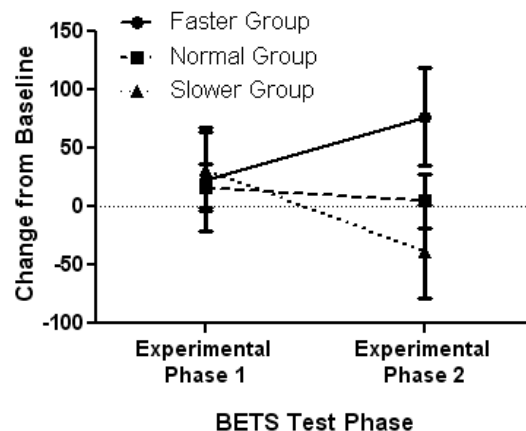
**Figure 9.** Mean accuracy and speed improvement in the mental rotation task across the three conditions (puppet, Xbox and keyboard).

Overall, these results suggest that the embodied mapping between a player and avatar, provided by the puppet interface, leads to performance advantages and has positive cognitive effects (see Mazalek et al., 2011).

#### 4) Affecting Player Artistic Expression using the Puppet Interface [Y3]

The main purpose of this experiment was to determine if experience with the embodied puppet influences the manner in which participants express themselves through sketching. To this end, we compared the speed and pressure of drawing performance of three groups of 10 participants who completed a sketching task before and after playing the teapot video game with the puppet. The key manipulation was that the different groups played the game under 3 different real:virtual mapping conditions. For the first (Faster) group, the movements of the avatar in the virtual world were faster than those of the participant. For the second (Slower) group, the movements of the avatar in the virtual world were slower than those of the participant. For the final (Normal) group, the movements of the avatar in the virtual world were mapped on a 1:1 basis with those of the participant.

The results of study revealed that, as predicted, the relative mapping condition altered the manner in which the participants drew the pictures. Although the mapping did not affect the speed of the drawing, it did significantly influence the pressure the participants exerted on the drawing surface. Specifically, there was a significant decrease in pressure in the performance of the group who executed the game in the Slower condition. Likewise, there was a trend towards an increase in pressure in the group that played in the Faster condition (although this difference did not reach statistical significance ( $p < .11$ )). Importantly, note that the pressures from the group who performed in the Normal condition did not change. Overall, these data provide preliminary evidence that the manner in which your movements with puppet map on to the movements of the avatar in the virtual world can have carry-over effects for your subsequent movements in the real world, including the way in which you express yourself.



**Figure 9.** Changes in pressure from baseline in the drawings made by participant in the three different mapping conditions: normal, slower, and faster. There was a significant decrease for the slower condition, and a trend towards an increase in the faster condition. The normal condition did not change.

#### 5) Piloting Puppet Acceptability with Stroke Patients [Y3]

Our preliminary findings with two stroke survivors indicate that they can safely and effectively utilize a puppet controlled virtual avatar to reach for external objects in a virtual game. One of the stroke survivors using the puppet interface made two important comments. First, she said: "I just felt like we were one and the same person, 'cause I felt like that was me." Then, contrasting the puppet with the Wii Remote, she said: "[with the Wii] I'm just handling a piece of machinery, but with the puppet... it would be like it was my friend." This qualitative difference in her experience suggests that transferring her own movements brought the character's movements closer to her actual experience, thus bringing the character closer to her 'self'.

## Summary

Overall, the results show an effective translation of self to the character, suggesting that we indeed project ourselves to the movements of characters whose movements derive in second order from our own body memory; probably through a common coding system. The results of our experiments also show that the puppet interface provides better interaction while controlling virtual characters, and this better interaction has beneficial cognitive effects, compared to the other existing interfaces. Building on these results, we believe we can develop new media and new interfaces that utilize this connection.

### 3. What research and teaching skills and experience has the project helped provide to those who worked on the project?

The project covers three main areas: cognitive science, interface design, and virtual world research. Throughout the project we improved the research horizon and skills of all participants through our interdisciplinary work.

**Cognitive Science.** The collaboration with the cognitive scientists helped the graduate students understand the biological mechanisms underlying human movement, and how research findings in this area could be applied to develop new media. The interaction also helped in understanding the research methodologies used in this area and developing an appreciation for the experimental rigor involved. It is worth mentioning here that reviewers of our papers particularly highlighted this aspect of our papers. Further, the collaboration has led to a possible extension of the puppet into physiotherapy applications, which we are exploring currently with brain-machine interface and medical rehabilitation experts.

**Interface design.** Students and faculty gained new knowledge in the practical design and maintenance of a sensor-equipped tangible puppet interface. We have gained a better understanding of how to stabilize the sensor technologies and increase the robustness of the interface for use by a large number of people during our experiments. The mental rotation experiment with the three different interfaces also helped develop a better understanding of how control of the avatar interacted with cognition and perception.

**Virtual worlds.** We have learned to optimize the open source 3D engine developed in the first year. This includes coding of an experimental game as well as inclusion of evaluation tools for a user's performance. Students assigned to the 3D part of the project were actively involved in the design of the experiments as well as in the necessary adjustments of the software to cater for the newly designed tests. The interdisciplinary approach and continuous experimental work of our project provided valuable references to better understand our relationship to these virtual 3D spaces.

The biggest advance was the combination of our three main research areas and the way we were able to realize our project within the various conditions of the individual fields. For example, the design of a useful cognitive test as an interactive game setting within the virtual world and its connection to the physical puppet interface was a challenge that needed each of our three fields to understand and respond to the others. Also, the close collaboration led to the development of self-recognition as a novel way of testing personalization of virtual avatars.

Due to the continuous experimental evaluation, all students involved in the project developed practical research skills. These include the design, implementation, and conduct of experiments that investigate the interdisciplinary research area we are targeting. Because this research approach demanded a combination of cognitive sciences, interface design, hardware-, and software-development, all students gained experience in multiple disciplines. For example, they learned how to transfer our initial experimental set up from a 2D / video setting onto a 3D world test environment. They also iterated on the puppet interface, gaining knowledge about improved sensor stability and design. They participated in the design, implementation and testing of multiple experiments. These included standard cognitive science tests (e.g. measuring mental rotation abilities) as well as innovative digital testing environments (e.g. using three different interfaces to control a 3D puppet). Thus, they became familiar not only with traditional research tools but were also part of newer research tools developed in the course of the

project. Below we separate the main graduate students involved in the project.

#### **Graduate students:**

Paul Clifton took the lead on iterating the design and development of the puppet interface and greatly enhanced his practical and technical design skills in the process. He also served as a mentor to the first year MS student who joined the project to help with the tangible interface aspect of the project. He also further enhanced his experimental skills and was central to the running of both the movement projection and mental rotation experiments.

Matthew Drake was responsible for the porting of the 3D renderer to Unity which enhanced the flexibility of the virtual stage and game implementation greatly and familiarized him with state of the art 3D SDKs. He also implemented the recording feature of each virtual performance that was crucial in the evaluation of the game performances and that improved his practical work with data collection and evaluation. In addition, he assisted during the experiments in Y2 and Y3.

Andrew Quitmeyer assisted in the puppet interface refurbishment but his main responsibility was the 3D renderer. He added new elements, such as the programming of the moving cameras in the last experiment and the inclusion of evaluation tools, and maintained necessary features, such as the experimental game set up in the engine. He was also seminal during the experimental phase and the collection of data.

Firaz Peer joined the project in Y2 as a first year graduate student. He learned about the iterative tangible interface design and development process and greatly enhanced his skills in this area. He also learned about experimental methodology and assisted with data collection in the movement projection and mental rotation studies.

Geoffrey Thomas learned details not only on the hardware side of the puppet assembly and constructions but also on the software side of the input reading. In addition, he became familiar with the evaluation and testing software for the first semester study.

Tandav Krishna improved his technical skills in his work on the first puppet interface and was seminal in the initial studies of own body movement projection. He mainly worked on the development, set up, testing, and evaluation of this study.

#### **Undergraduate students:**

Martin Rojas joined as an undergraduate researcher in Y1 and deepened his knowledge particularly in the area of the 3D renderer. He continued this work into his own, closely related, project PuppetMan. Rojas gained undergraduate research experience during his participation in the project in the first semester and developed the work further into his defining capstone project in the following semester. He particularly developed an animation recorder based on game interfaces.

#### **4. What outreach activities have you undertaken to increase public understanding of, and participation in, science and technology?**

We presented our first findings at SIGGRAPH 2009 (August 4-6). In addition, we demoed the running prototype of the puppet interface at the SIGCHI 2010 GVU demo showcase (04/16/2010), the Turner Broadcasting demo day at Georgia Tech (05/04/2010) as well as at semesterly demo showcases hosted by the GVU Center and the Digital Media program at Georgia Tech. These demos were open to the public and generally accessible. Feedback during these presentations was overwhelmingly positive and the project has led to contacts to a local game developer (Games That Work) interested in the field of innovative interface design.

### III. Publications and Products

#### 1. What work have you published as a result of this work?

This work has resulted in two book chapters, two journal articles, and three full-length papers in conference proceedings. Additionally, one journal article for ACM Transactions on Computer-Human Interaction is currently under review.

##### Book chapters:

Mazalek, A., Chandrasekharan, S., Nitsche, M., Welsh, T., Clifton, P. (Forthcoming). Embodying Self in Virtual Worlds. *Reinventing Ourselves: Contemporary Concepts of Identity in Virtual Worlds*, A. Peachey, M. Childs (eds.). Springer.

Nitsche, M., Mazalek, A., Clifton, P. (Forthcoming) "Moving Digital Puppets," *Understanding Machinima*, J. Ng, J. Barrett (eds.), Continuum Press, London / New York.

##### Journal articles:

Mazalek, A., Nitsche, M., Chandrasekharan, S., Welsh, T., Clifton, P., Quitmeyer, A., Peer, F., Kirschner, F. (Forthcoming) "Recognizing Your Self in Virtual Avatars," *International Journal of Art and Technology (IJART)*.

Chandrasekharan, S., Mazalek, A., Chen, Y., Nitsche, M., Ranjan, A. (2010). Ideomotor Design: using common coding theory to derive novel video game interactions. *Pragmatics & Cognition*, 18 (2), 313-339.

##### Conference proceedings papers:

Mazalek, A., Chandrasekharan, S., Nitsche, M., Welsh, T., Thomas, G., Sanka, T. and Clifton, P. (2009). Giving your self to the game: Transferring a player's own movements to avatars using tangible interfaces. *Proceedings of the 2009 ACM SIGGRAPH Symposium on Video Games*, (New Orleans, Louisiana), ACM, New York, NY, 161-168.

Mazalek, A., Nitsche, M., Chandrasekharan, S., Welsh, T., Clifton, P., Quitmeyer, A., Peer, F. and Kirschner, F. (2010). Recognizing self in puppet controlled virtual avatars. *Proceedings of the 3rd International Conference on Fun and Games*, (Leuven, Belgium), ACM, New York, NY, 66-73.

Mazalek, A., Nitsche, M., Chandrasekharan, S., Welsh, T., Clifton, P., Quitmeyer, A., Peer, F., Kirschner, F. and Athreya, D. (2011). I'm in the game: Embodied puppet interface improves avatar control. *Proceedings of the Fifth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '11)*, ACM, New York, NY, 129-136.

##### Under review:

Chandrasekhara, S., Mazalek, A. Ideomotor Interactions: designs that exploit and extend embodied cognition. Currently under review for ACM Transactions on Computer-Human Interaction.

#### 2. What Web site or other Internet sites reflect this project?

<http://www.synlab.gatech.edu/projects/bdc/>

#### 3. What other specific products (databases, physical collections, educational aids, software, instruments, or the like) have you developed.

None.

## **IV. Contributions**

### **1. Contributions within discipline**

Our research on projection of own-body movement on abstracted movement visualizations and into puppet movements addresses the connection between a player/user and the controlled virtual character. This is a key question not only in research on interactive virtual environments but also in the area of interface design and common coding theory in cognitive science. A full paper of our findings was presented at SIGGRAPH 2009. This paper has been downloaded 270 times from the ACM digital library in the last 12 months alone, suggesting that the research could have a high impact on future work in this area.

The results from the experiment showing self-recognition when a participant's movements are translated to an avatar using the puppet was presented accepted at the ACM Fun and Games conference in 2010. The results of the mental rotation experiment was presented at the ACM Tangible, Embedded, and Embodied Interaction conference in 2011. A paper outlining our design approach, i.e. using common coding theory to develop novel video game interaction designs, was published in the Pragmatics and Cognition journal in 2011. Another paper summarizing the work from the beginning of the project up to the mental rotation experiment is due to appear soon in the International Journal of Art and Technology (IJART).

Our use of self-recognition as a metric for understanding a player's connection to the avatar offers a novel methodology, supporting an objective evaluation of the level of personalization of video game characters which informs discussions on personal and social media in this research field.

### **2. Contributions to other disciplines**

The puppet and the animation interface we have developed provide novel opportunities for research into human movement, particularly rehabilitation of patients with movement disorders. We are currently developing a project in this area with brain-machine interface and medical rehabilitation groups.

Our application of common coding to digital media design has provided an application focus to the embodied cognition approach in cognitive science. In Game Studies, it provides a theoretical basis for understanding the cognitive effects of character control and identification in video games, such as improvement in attention and mental rotation and close identification with avatars. The effects shown in our experiments support discussions in the arena of educational games and the Serious Games movement at large.

### **3. Contributions to education and development of human resources**

Our team is not only highly interdisciplinary but also multinational (American, Canadian, German, and Indian). The range of participants includes undergraduate students, Master of Science students in Digital Media and Human Computer Interaction, and PhD students in Digital Media. The team is also international and interconnected to our collaborators in Toronto and Inverness. We hope to further support this kind of networked approach to allow students to participate in a largely international research atmosphere and allow for multiple perspectives as well as a high level of quality.

### **4. Contributions to physical, institutional, and information resources for science and technology**

N/A

### **5. Contributions to the public welfare beyond science and engineering**



N/A

## **V. Special Requirements**

**1. A brief summary of the work to be performed during the next year of support if changed from the original proposal.**

N/A

**2. Do special terms and conditions of your award require you to report any specific information that you have not yet reported?**

No.

**3. Do you anticipate that more than twenty percent of the funds under your NSF award will remain unobligated at the end of the period for which NSF currently is providing support?**

No.

**4. Has there been any significant change in animal care and use, biohazards, or use of human subjects from what was originally approved (or approved later)?**

No.